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PROCESS FOR REDUCTION OF METAL OXIDE TO METAL AND APPARATUS AND COMPOSITE
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A process for the reduction of metal oxide fines to a metal containing product, the process including the steps of:

- (a) mixing a carbonaceous material with said metal oxide fines and, optionally, a binder and/or water, to produce a cohesive mass;
- (b) compacting the cohesive mass to produce a composite body;
- (c) drying the composite body;
- (d) heating the composite body in a reducing atmosphere at a temperature and for a time sufficient to form a reductant from said carbonaceous material which reduces a predetermined amount of the metal oxide to the metal;
- (e) contacting the hot, reduced composite body from step (d) with an oxygen-containing gas to combust a sufficient quantity of the carbonaceous material so as to raise the temperature of the body to the melting temperature of the metal, and thereby form a molten metal containing phase; and
- (f) cooling the molten-metal containing phase to produce said metal containing product.

The invention also provides a composite and apparatus for use in the process of the invention.

ABSTRACT

A process for the reduction of metal oxide fines to a metal containing product, the process including the steps of:

- 5 (a) mixing a carbonaceous material with said metal oxide fines and, optionally, a binder and/or water, to produce a cohesive mass;
- (b) compacting the cohesive mass to produce a composite body;
- (c) drying the composite body;
- (d) heating the composite body in a reducing atmosphere at a temperature and
10 for a time sufficient to form a reductant from said carbonaceous material which reduces a predetermined amount of the metal oxide to the metal;
- (e) contacting the hot, reduced composite body from step (d) with an oxygen-containing gas to combust a sufficient quantity of the carbonaceous material so as to raise the temperature of the body to the melting temperature of the metal,
15 and thereby form a molten metal containing phase; and
- (f) cooling the molten-metal containing phase to produce said metal containing product.

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Complete Specification for the invention entitled:

**PROCESS FOR REDUCTION OF METAL OXIDE TO METAL
AND APPARATUS AND COMPOSITE FOR USE IN THE PROCESS**

Our Ref.: IRN 378848

The following statement is a full description of this invention, including the best method of performing it known to applicant(s):

PROCESS FOR REDUCTION OF METAL OXIDE TO METAL
AND APPARATUS AND COMPOSITE FOR USE IN THE PROCESS

Field of the Invention

5 This invention relates to a process for the reduction of metal oxide to metal or metal-containing product. The invention is suitable for the reduction of metal oxide fines which are the waste by product of mining or metal processing. The invention is particularly suitable for the production of steel from iron oxide waste, such as waste iron ore fines and/or mill scale.

10

Background of the Invention

Large quantities of waste material are generated by the mining and metal processing industries each year. A great proportion of the waste material exists in the form of metal oxide fines. These fines are difficult and/or expensive to
15 handle or process and are often simply dumped or disposed of to landfill. Accordingly, large quantities of potentially valuable metal source materials are wasted each year.

There is clearly a need for a process which utilises metal oxide fines, such as waste metal oxides, to produce a useful metal containing end-product.

20 Australian Patent Application AU-A-54395/86 discloses formation of composite pellets formed by extruding a plastic mixture of finely divided metal oxide ore and attritioned brown coal. The metal oxide-coal composite pellets may then be used in metal smelting processes by heating to reduce the metal oxide to the metal. However the reduction and smelting steps disclosed in AU-A-54395/86
25 require provision of external heating means in order to sufficiently heat the pellets. This in turn leads to increased energy consumption, increased expense and the requirement for specialised apparatus.

Furthermore, the end product of the smelting operation disclosed in AU-A-54395/86 would contain unacceptably high impurity levels and would therefore
30 require further refining to produce a high purity and chemically stable metal end product.

It is therefore an object of this invention to provide a process for the extraction of metal from metal oxide fines, particularly waste metal oxide fines, which overcomes or at least alleviates one or more disadvantages of the prior art.

5 It is also an object of this invention to provide a composite body suitable for use in a metal smelting operation.

It is a further object of the invention to provide simple, easily controllable and economic processing of metal oxide waste, which can be operated on a small scale, to produce a useful and high purity metal product.

10 It is a still further object of this invention to provide apparatus for use in the reduction of metal oxide to metal.

SUMMARY OF THE INVENTION

15 According to the present invention, there is provide a process for the reduction of metal oxide fines to a metal containing product, the process including the steps of:

(a) mixing a carbonaceous material with said metal oxide fines to produce a cohesive mass;

(b) compacting the cohesive mass to produce a composite body;

20 (c) drying the composite body;

(d) heating the composite body in a reducing atmosphere at a temperature and for a time sufficient to form a reductant from said carbonaceous material which reduces a predetermined amount of the metal oxide to the metal;

25 (e) contacting the hot, reduced composite body from step (d) with an oxygen-containing gas to combust a sufficient quantity of the carbonaceous material so as to raise the temperature of the body to the melting temperature of the metal, and thereby form a molten metal containing phase; and

(f) cooling the molten-metal containing phase to produce said metal containing product.

30 The present invention further provides an apparatus for use in the process of the present invention, said apparatus including:

a chamber for receiving a mixture of metal oxide and carbonaceous material, said chamber being heatable to at least a temperature sufficient to



convert at least some of the carbonaceous material to a combustible gas and to effect reduction of said metal oxide to its metal;

heating means for heating said chamber to said temperature;

5 a gas burner for maintaining said chamber at said temperature in the absence of heat from said heating means; and

a gas conduit extending from said chamber to said gas burner for supplying said combustible gas to said gas burner during operation of the apparatus.

10 According to the present invention, there is also provided a composite body for use in the process of the invention, said composite body including metal oxide fines and carbonaceous material, wherein the amount of carbonaceous material in the composite body is at least sufficient to:

(a) effect reduction of a predetermined amount of metal oxide to its
15 metal, when the composite body is heated to a reduction temperature; and

(b) raise the temperature of the composite body to the melting temperature of the metal when the hot reduced composite body of (a) is contacted with an oxygen containing gas.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

20 Where the metal oxide fines and carbonaceous material contain significant levels of impurities, it is preferably to add a flux to the composite of the invention, in order to form a slag phase containing impurities during melting of the metal. The molten metal containing phase can then be separated from the slag phase and cooled to give a metal-containing product of the desired purity.

25 If flux is added to the composite, it can be either added separately, preferably in powder form, to the composite body, prior to melting the metal, or, preferably, it can be mixed with the metal oxide fines and carbonaceous material of step (a), such that the composite body subsequently formed is self-fluxing. Alternatively, a flux precursor, such as uncalcined limestone, can be added to the
30 mixture in step (a). During reduction of the composite body subsequently formed, the flux precursor undergoes calcination to form the flux. In the case of uncalcined limestone, it undergoes calcination to form lime during the reduction



step. Adding uncalcined limestone to the composite body is advantageous because uncalcined limestone is less expensive than lime, thus making the composite more economical to produce.

Preferably, the composite body is in the form of a pellet. More preferably, the pellet is formed by extrusion of the cohesive mass.

The metal oxide fines may comprise any ore fines or mill scale. Examples of metal oxides suitable to use in the reduction process are iron oxide ores, such as hematite (Fe_2O_3) and magnetite (Fe_3O_4 , FeO), chromite ores (FeCr_2O_4 , MgCr_2O_4), and base metal ores, such as zinc ores.

The apparatus of the invention preferably includes a safety relief valve in the gas conduit, operable to relieve pressure in the gas conduit once the gas pressure exceeds a predetermined value.

It is preferred that the apparatus includes a furnace chamber which is externally heated by any suitable means such as gas flame, resistance heating etc. Also preferably, the apparatus includes a heat resistant container for location within the chamber, which container is used for receiving the mixture of metal oxide and carbonaceous material. In such an arrangement, the gas conduit extends from the heat resistant container to a gas burner for heating the furnace.

Once the heating means has heated the furnace and mixture of reactants to the required temperature, carbon monoxide and other combustible gases are evolved from the reactants and pass through the gas conduit to the gas burner. The furnace heating means and gas burner may be one and the same, or different features. Once evolution of the combustible gases commences, the gas burner may be lit and the heating means (if a separate feature) turned off. The gas burner can then be used to maintain the furnace temperature at the desired level.

The invention is particularly suited for the reduction of iron oxide fines and it is on this application that the following discussion will largely concentrate. However, a skilled addressee will understand that the invention is not to be limited to such use.

The iron oxide fines may be derived from mine or quarry rejects or from steel processing mill scale (a byproduct of the steel rolling process) the latter of which

comprises a mixture of FeO and Fe_3O_4 . The particle size is preferably sand size or less and may be less than 10 mesh (approximately $1500\mu\text{m}$). There is no lower limit on particle size and, in fact, the smaller the better as reduction rate increases with decreasing particle size.

- 5 The carbonaceous material preferably has a high surface area and small grain size in order to maximise the chemical reactivity of the reductant.

The carbonaceous material provides the fuel for subsequent steps of the process. Accordingly, the composites are self-fuelling. The carbonaceous material also provides the reductant to reduce the metal oxide.

- 10 Preferred carbonaceous materials are finely divided brown coal or peat because of their cellular structure resulting in high chemical reactivity. Using low grade coal or peat instead of higher grade coal (as in traditional direct reduced iron processes) is advantageous economically, due to the lower cost of low grade coal or peat. Brown coal or peat also have desirable physical properties, in particular their ability to plasticise under mechanical shear which enables the production of cohesive pellets formed by extrusion. Without wishing to be limited to a particular mechanism of formation, it is believed that shearing causes attrition of the brown coal or peat particles resulting in conversion of finely dispersed water in the structure to a bulk liquid phase, and polymerisation of phenolic rings present in the brown coal causing the coal or peat to become wet and plastic. Shearing also produces large numbers and areas of freshly cleaved coal surfaces, thereby maximising the physical association of coal/peat particles with metal oxide particles which in turn enhances the rate of the reduction reaction.

- 20 Alternatively, the carbonaceous material may comprise a higher grade coal or some other finely divided active carbon-source material, such as sawdust. In this case, it may be necessary to add a binder and/or water to the mixture of metal oxide and carbonaceous material so as to produce a cohesive mass able to be extruded into pellets.

- 30 Whatever the type of carbonaceous material, it may be necessary to add additional water to the mixture of step (a) so as to produce the desired consistency of the plastic mass.

An optional third reactant in addition to the metal oxide and carbonaceous material is a flux or a flux precursor for the subsequent formation of a slag phase during step (e). A flux or flux precursor is preferably added where removal of any impurities from the molten metal phase is desired. Impurities from the metal oxide source and the carbonaceous source react with the flux and are incorporated into the slag phase, thereby minimising the amount of impurities in the molten metal formed in step (e). The flux or flux precursor may comprise a calcium or magnesium oxide or hydroxide, or a carbonate such as limestone (CaCO_3) or magnesite (MgCO_3). It is preferred that the flux or flux precursor is incorporated into the composite body.

The relative quantities of the carbonaceous material, metal oxide and flux or flux precursor (if present) will vary depending on the desired end result. The amount of carbonaceous material should be such that, when combusted, the carbonaceous material provides at least sufficient heat for carbonisation of the brown coal or peat, reduction of the iron oxide and for the final melting of the reduced pellets. In the case where the metal oxide is iron oxide, and it is desired to produce steel as the metal-containing end product, there should preferably also be sufficient carbonaceous material to provide the desired amount of carbon in the end product steel. The amount of flux should be sufficient to combine with and remove substantially all of the impurities in the molten metal.

Based on one part by weight of metal oxide, the quantity of carbonaceous material in the mixture is preferably at least 1/2 part. More preferably, there is at least 2/3 part of carbonaceous material per part of metal oxide. The maximum quantity of carbonaceous material is preferably two parts per part of metal oxide. The amount of flux material is preferably up to 1/2 part per part of metal oxide.

The carbonaceous material, metal oxide fines, flux (if desired) and optionally, binder are mixed together with additional water (if necessary) and subjected to sufficient agitation and/or shearing in order to produce a substantially homogeneous, cohesive mass. Where the carbonaceous reductant is brown coal, subjecting the mixture to a shearing force during mixing causes attrition of the brown coal and formation of a plastic mass.

The cohesive mass is then compacted into pellets. This step is preferably achieved by extrusion, such as by using a screw extruder. Preferably, the pellets are cylindrical, having a cross-sectional diameter of 1 to 2cm.

The pellets are then dried in order to remove substantially all of their water.

5 Drying may be achieved by simply allowing the pellets to stand in air (such as on drying racks) at ambient temperature for a sufficient period of time. Alternatively, drying may be assisted by the application of heat. However a slow drying rate is preferred as this enhances pellet strength. Preferably, the pellets are allowed to air dry for a period of from 24 to 48 hours.

10 The dried pellets are next heated in a reducing atmosphere at a temperature and for a time sufficient to reduce a predetermined amount of the metal oxide to the metal. Preferably substantially all of the metal oxide is reduced. Where the pellets contain an iron oxide, this is reduced to iron. Typically, the reduction process takes place in a furnace. Preferably, the pellets are placed in a closed
15 stainless steel retort which is then placed in a preheated gas fired furnace. The reaction is initiated by an external heating means. However, once the combustible gases, in particular carbon monoxide gas, are evolved from the carbonaceous material, they are advantageously fed back into the combustion space of the furnace via a recycling conduit for combustion and provision of some
20 to all of the heat for the rest of the reduction process. Thus, the external energy requirements for the reduction process can be minimised.

Typically, the heating rate of the pellets is controlled so that the pellets reach a reduction temperature in 3 to 4 hours. Preferably, the reduction temperature reached in 2 to 3 hours. More preferably, the reduction temperature is attained in
25 2 to 2 1/2 hours.

Where the pellets contain iron oxide, the reduction temperature is typically between 850 and 1050°C. Preferably, the pellets are then held at the reduction temperature for at least another hour. The heating rate of the pellets may be indirectly controlled by varying the amount of air fed to the combustion chamber.

30 Without wishing to be limited to a particular reduction mechanism, it is believed that heating the carbonaceous material results in the evolution of carbon

monoxide gas (CO). The carbon monoxide gas then reacts with and reduces the iron oxides to iron. At the same time, carbon monoxide is oxidised to carbon dioxide gas (CO₂). The latter then reacts with carbon in the carbonaceous material to form further carbon monoxide gas.

5 The temperature and time of reduction will depend on the nature of the metal oxides. For iron oxides containing ferric oxide, such as hematite (Fe₂O₃), reduction takes place around 950°C. For difficult to reduce materials such as ferrous oxides, for example magnetite (Fe₃O₄, FeO) and mill scale, the temperature of reduction is around 1050°C. Preferably, the final temperature is
10 maintained for a sufficient period of time to achieve substantially complete reduction of the metal oxide. Reduction is usually complete after 1 to 1 1/2 hours at temperature. Complete reduction may be detected by the waste gas discharge being insufficient to maintain the flame of the waste gas burner. It is to be noted that the temperature of reduction is considerably lower than the temperature of
15 iron ore reduction using high grade coal (typically around 1150°C or higher). Any suitable equipment can be used for the reduction operation, eg. Rotary Kiln, Batch Retort, Multiple hearth furnace, Fluidised Bed etc.

The reduction process can be advantageously accelerated by controlled injection of limited amounts of one or more of air, water, steam and oxygen.

20 Once reduction of the metal oxide to the metal is complete, the hot pellets are contacted with oxygen-containing gas in order to combust the remaining carbonaceous material in the pellets and thereby melt the metal. Preferably, the oxygen-containing gas is oxygen gas. However, other oxygen-containing gases, such as air, may be used instead. Preferably, the reduced pellets are removed
25 from the reduction furnace and placed in a preheated crucible positioned in an open topped furnace. An antioxidant, such as dried coal, and/or a small quantity of crushed slag may be added to the pellets. The oxygen-containing gas may be introduced via an oxygen lance, such as through a mild steel pipe. Where a mild steel pipe is used, a small amount of the pipe may melt during the melting
30 process and the pipe is preferably weighed before and after oxygen addition to determine how much mild steel has been incorporated in the melt. Alternatively, a cooled oxygen lance, such as a water-cooled oxygen lance, may be used,

which reduces the level of mild steel incorporated into the melt. Combustion of the carbonaceous material with oxygen raises the temperature of the pellets sufficiently to melt the metal and to form a slag from the flux and impurities. In the case of iron, the temperature of the pellets is increased to around 1550°C at which temperature molten iron forms. Where limestone is used as a flux or flux precursor, the slag phase normally comprises calcium silicates. As the iron melts and sinks to the bottom of the crucible, the slag separates out and forms a layer on the surface of the molten metal. Injection of the oxygen-containing gas continues until the desired carbon content in the molten iron is achieved. Oxygen injection ceases and the molten steel is preferably killed, for example by pushing a small amount of aluminum into the melt. Accordingly, by suitable refining of the metal, steel ready for casting can be produced.

Accordingly, the melting and refining of the metal can be achieved simply by the injection of an oxygen-containing gas without the need for external heating. Furthermore, the step of reacting excess carbon in the melt with oxygen is advantageous in that it results in separation of a metal phase and an impurity-containing slag phase, which enable a wide variety of starting materials, with varying levels of impurities to be used.

After separating the molten metal phase from the slag, the molten metal is typically cast and cooled to produce the metal product. Casting and cooling of molten steel can be achieved by any suitable traditional iron and steel making techniques. An advantage of the resultant cast steel product which can be produced from the process of the present invention is that it is dense and inert.

The resultant steel end product which may be produced by the process of the present invention is dense and inert and is suitable for casting into a finished or semi finished product. It can be used to provide a clean, high quality scrap steel for use in Electric Arc Furnaces and other Steel making processes.

Traditionally, the production of steel is a two stage process. In the first stage iron ore, usually comprising high grade iron oxides, is reduced by high grade coal in a blast furnace. A flux, such as limestone (CaCO_3) is also added to the blast furnace in lump form which combines with impurities to form a slag.

Molten iron is tapped off and may be cast into moulds to form impure iron called pig iron.

Temperatures in the blast furnace exceed 1350°C and can be as high as 1850°C. The blast furnace is very large - up to 100m high having a hearth up to 11m. High throughput processing - of the order of 4 million tonnes per year or more - is accordingly required for economic viability.

In the second stage, the pig iron is processed to form steel. There are a number of different steel making processes, all of which involve further removal of impurities and optimisation of carbon levels in the steel. A widely used steel-making process in Australia is the Basic Oxygen steel-making process.

The process of the present invention enables use of low grade feed material, such as cheap low grade iron ore, iron ore fines and brown coal and still achieves a high purity end product. This is to be compared with the end product from Traditional Iron making plants which, despite having a high purity lump iron oxide feed, contains inorganic impurities. Accordingly, further processing and refining, and therefore expense, is required to produce a high purity steel product. Furthermore, the end product from Traditional Direct Reduced Iron Plants is "sponge iron" which has a propensity to reoxidise causing storage, transport and handling problems. In contrast, the end product from the present invention can be a chemically stable steel suitable for bulk transport and outside storage.

The process of the invention can be used with simple low cost equipment, meaning that the process is capable of economic operation at relatively low throughputs. Manufacturing plants economically processing as little as 5,000 to 10,000 tonnes per year are possible. This figure is substantially lower than the 4 million tonnes or greater which is required for traditional Blast Furnace, Basic Oxygen steel making route in order to achieve economic viability.

DESCRIPTION OF DRAWING

The invention will become more readily apparent from the following exemplary description in connection with the accompanying drawing and Examples:

The accompanying Figure is a cross-sectional view of an example of a furnace used to effect reduction of the pellets of the present invention.

In the accompanying Figure, heating furnace 10 includes refractory lining 12 and is heated by gas burner 13. The waste by products of gas burner 13 are exhausted through waste gas flue 14. The emission of waste gases is controlled by operation of control damper 16.

At the open end 18 of furnace 10 is positioned an annular plug 20 of ceramic fibre insulation 22. Plug 20 has a centrally located axial aperture through which is suspended batch retort 24 containing pellet charge 28. Batch retort 24 consists of a stainless steel container 26, with a diameter of approximately 150mm and a length of about 500mm, and a radial flange 29 at the open end of steel container 26. Batch retort 24 is closed by lid 34. Lid 34 is in the form of a 150mm deep cup filled with insulating material and is secured to radial flange 29 by means of bolts 30.

Lid 34 accommodates thermocouple 36 and reaction gas vent pipe 38. The lid 34 also includes retort lifting lug 40 for facilitating removal of retort 26 from furnace 10.

Thermocouple 36 passes through lid 34 and into pellet charge 28. The cold end of thermocouple 36 is electrically connected to temperature gauge 42 for measuring the temperature of pellet charge 28.

Reaction gas vent conduit 38 extends from opening 44 in lid 34 to reaction gas burner nozzle 46 positioned at aperture 48 in side wall 50 of furnace 10. Accordingly, combustible gases produced during the reduction of the pellets, such as carbon monoxide, can be utilised as fuel for the gas burner nozzle 46. Thus, during operation of the furnace, gas burner 13, fuelled by an external gas supply (not shown), is used to heat the pellet charge 28 to the desired temperature to achieve reduction. Once reduction commences combustible gases are produced and fed as fuel to gas burner nozzle 46. At such time, gas burner 13 can be turned off and gas burner nozzle 46 used instead to heat the furnace. Accordingly, the amount of external fuel supply required to heat the furnace can be minimised.

Reaction gas vent conduit 38 branches at 38a where a short length of conduit leads to a safety relief valve 52. Should the gas pressure in conduit 38 exceed a predetermined level, relief valve 52 will automatically open to relieve pressure in the conduit 38.

- 5 Shut off valve 54, also located in gas vent conduit 38, is operable to shut off the flow of the reaction gas to the gas burner nozzle 46.

The following Examples illustrate, in detail, embodiments of the invention.

EXAMPLE 1

- 10 6.8kg of Brown Coal, 10.2 kg of Savage River Magnetite and 3.4kg of limestone were placed in a double blade mixer and mixed for approximately 30 minutes until a plastic mass was formed. Accordingly, the mass ratio of coal: iron ore: flux was 1:1.5 : 0.5. All the starting materials were below 6mm particle size. Sufficient water, in this instance, 3.5 litres, was added to achieve the desired
15 plasticity without making the mixture too soft for effective pelletisation. The plastic mixture was then transferred to a single auger extruder having three 20mm discharge nozzles. As the material left the nozzles it was broken into short lengths by hand and the resultant pellets spread out upon trays and allowed to air dry. Although relatively weak as extruded the pellets gained strength and
20 hardened within a few minutes. If required the drying process can be accelerated by placing the trays in a gently flowing stream of warm air. The trays were weighed each day to monitor the drying process.

- The reduction retort, shown schematically in the Figure was used for the reduction process. A small quantity of coal was placed in the bottom of the retort
25 to assist emptying out the reduced pellets. 2kg of the air dried pellets were placed in the retort and the lid sealed. The retort was then placed in a specially constructed gas fired furnace which had been preheated for 1.5 hours. The thermocouple was inserted and the temperature noted. The temperature was then recorded at 15 minute intervals throughout the process. The furnace flame
30 was adjusted to achieve a temperature of around 900 degrees Centigrade in 2hrs. At this temperature the majority of the coal volatiles had been released and the reduction reactions were proceeding. The colour of the flame at the end of the waste gas vent pipe indicated whether the reduction reactions were

proceeding (yellow flame indicates reduction is proceeding). The temperature rose slowly to 1070°C at which stage the flame went out and the reduction was judged to be near completion. The furnace was turned off and the retort opened. The contents were quickly poured into a preheated silicon carbide crucible held in a gas fired muffle furnace. A small quantity of crude slag and dried brown coal were placed on top of the pellets to act as a slag starter and to prevent reoxidation of the hot reduced pellets. Pure oxygen was then blown into the crucible from a cylinder through a mild steel lance. Sufficient oxygen was used to melt and refine the steel produced. Some of the lance melted into the mixture and some was oxidised. However, a mass balance calculation on the materials showed that the majority of the steel produced came from the iron ore used. Excess oxygen was then removed from the steel by the addition of aluminium in order to obtain a sample suitable for spectrographic analysis.

The crucible was allowed to cool. When cold the contents were removed and the slag broken away from the steel. After weighing, the sample was cut in two for visual examination and analysis. The chemical composition of the final steel product was (in weight %): 96.7% Fe, 0.445% C, 0.18% Mn, 0.266% Si, 0.6% S, 1.61% W and 0.013% residuals.

20 EXAMPLE 2

A quantity of iron ore fines was taken from the open cut at the Seven Mile iron ore deposit at Nowa Nowa. Of this material, 10.09 kg was placed in a double blade mixer together with 14.13 kg of Brown Coal fines. After mixing for approximately 20 minutes, 3.5 litres of water was added and mixing continued for approximately a further 15 minutes until a suitable plastic consistency was achieved. The resulting material was extruded to form cylindrical pellets 20 mm in diameter using a bench scale single auger extruder. The pellets were spread out on trays and allowed to air dry. 1.81 kg of dried pellets and 0.34 kg of Buchan limestone fines were placed in the test retort and the top closed. The retort was then placed in the furnace which had been preheated for 1.5 hr. Heating was continued at a rate such that the contents of the retort reached a temperature of 950 degrees Centigrade in 3 hr. At this time the waste gas was insufficient to

sustain a flame at the discharge nozzle. Heating was maintained for a further 75 minutes, after 15 minutes the temperature was 1003°C. The gas firing rate was reduced and the temperature fell slowly to 957 degrees at the end of the reduction phase.

- 5 The gas was turned off and the retort opened, the contents were quickly transferred to the preheated silicon carbide crucible held in the open topped muffle furnace. A small quantity of fine dried coal and crushed slag was poured on top of the hot pellets to prevent reoxidation and act as a slag starter. Oxygen from a standard commercial cylinder and pressure regulator was injected to the
10 mixture through a mild steel lance. Oxygen addition was continued until the material had melted, at which time sufficient aluminium rod was pushed into the melt to kill the steel. After being allowed to cool the contents of the crucible were tipped out and the slag broken away from the steel. After weighing the steel was prepared for analysis by spart erosion spectrometer. The sample contained
15 98.5% iron.

Finally, it is to be understood that, although the invention has been described with particular reference to the foregoing Example and drawing, it will be clear that various modifications and improvements may be made without departing from the spirit and scope thereof.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

- 5 1. A process for the reduction of metal oxide fines to a metal containing product, the process including the steps of:
- (a) mixing a carbonaceous material with said metal oxide fines to produce a cohesive mass;
 - (b) compacting the cohesive mass to produce a composite body;
 - 10 (c) drying the composite body;
 - (d) heating the composite body in a reducing atmosphere at a temperature and for a time sufficient to form a reductant from said carbonaceous material which reduces a predetermined amount of the metal oxide to the metal;
 - (e) contacting the hot, reduced composite body from step (d) with an
 - 15 oxygen-containing gas to combust a sufficient quantity of the carbonaceous material so as to raise the temperature of the body to the melting temperature of the metal, and thereby form a molten metal containing phase; and
 - (f) cooling the molten-metal containing phase to produce said metal containing product.
- 20 2. The process of claim 1, wherein in step (a), said carbonaceous material and said metal fines are further mixed with a binder and/or water to produce said cohesive mass.
3. The process of claim 1 or 2, wherein said metal oxide fines comprise ore fines and/or mill scale.
- 25 4. The process of any preceding claim, wherein the metal oxide fines include iron oxide bearing waste material.
5. The process of any preceding claim, wherein the carbonaceous material is finely divided brown coal or peat.
6. The process of any preceding claim, wherein the metal oxide fines
- 30 comprise iron oxide, the metal containing product is steel and the quantity of said carbonaceous material is sufficient to provide the desired amount of carbon in the steel.



7. The process of any preceding claim, wherein the amount of carbonaceous material in the composite is at least 1/2 part by weight per 1 part of metal oxide.
8. The process of any preceding claim, wherein the amount of carbonaceous material in the composite is between 2/3 and 2 parts by weight per 1 part of metal oxide.
9. The process of any preceding claim, wherein the metal oxide fines have a particle size of less than 1500µm.
10. The process of any preceding claim, wherein step (a) further includes mixing a sufficient quantity of a flux or flux precursor with the carbonaceous material and metal oxide fines such that the composite body is self-fluxing and that a slag phase is formed during step (e).
11. The process of claim 10, wherein said flux or flux precursor is selected from the group comprising oxides, hydroxides and carbonates of calcium and magnesium.
12. The process of claim 10 or 11, wherein the flux precursor comprises uncalcined limestone fines.
13. The process of any one of claims 10 to 12, wherein the amount of flux or flux precursor is less than or equal to 1/2 part by weight per part of metal oxide.
14. The process of any preceding claim, wherein said compacting in step (b) comprises extruding the cohesive mass to produce a pellet.
15. The process of any preceding claim, wherein the rate of heating said composite body in step (d) is such that the composite body reaches a temperature of between 850 and 1050°C in 2 to 2 1/2 hours.
16. The process of any preceding claim, wherein the melting temperature of the metal in step (e) is around 1550°C.
17. An apparatus for use in the process of claim 1, said apparatus including:
 - a chamber for receiving a mixture of metal oxide and carbonaceous material, said chamber being heatable to at least a temperature sufficient to convert at least some of the carbonaceous material to a combustible gas and to effect reduction of said metal oxide to its metal;



heating means for heating said chamber to said temperature;

a gas burner for maintaining said chamber at said temperature in the absence of heat from said heating means; and

5 a gas conduit extending from said chamber to said gas burner for supplying said combustible gas to said gas burner during operation of the apparatus.

18. The apparatus of claim 17, further including a heat resistant container for location within said chamber, said heat resistant container for receiving said
10 mixture of metal oxide and carbonaceous material, wherein in use, said gas conduit extends from said heat resistant container to said gas burner.

19. The apparatus of claim 17 or claim 18, further including a safety relief valve, in said gas conduit, operable to relieve pressure in the gas conduit when gas pressure exceeds a predetermined value.

15 20. A composite body for use in the process of claim 1, said composite body including metal oxide fines and carbonaceous material, wherein the amount of carbonaceous material in the composite body is at least sufficient to:

(a) effect reduction of a predetermined amount of metal oxide to its metal, when the composite body is heated to a reduction temperature; and

20 (b) raise the temperature of the composite body to the melting temperature of the metal when the hot, reduced composite body of (a) is contacted with an oxygen containing gas.

21. The composite body of claim 20, further including a binder.

22. The composite body of claim 20 or 21, further including a sufficient quantity
25 of flux, or flux precursor, to form a slag phase when the temperature of the composite is raised to the melting temperature of the metal.

23. The composite body of claim 22, wherein said flux of flux precursor is selected from the group comprising oxides, hydroxides and carbonates of calcium and magnesium.

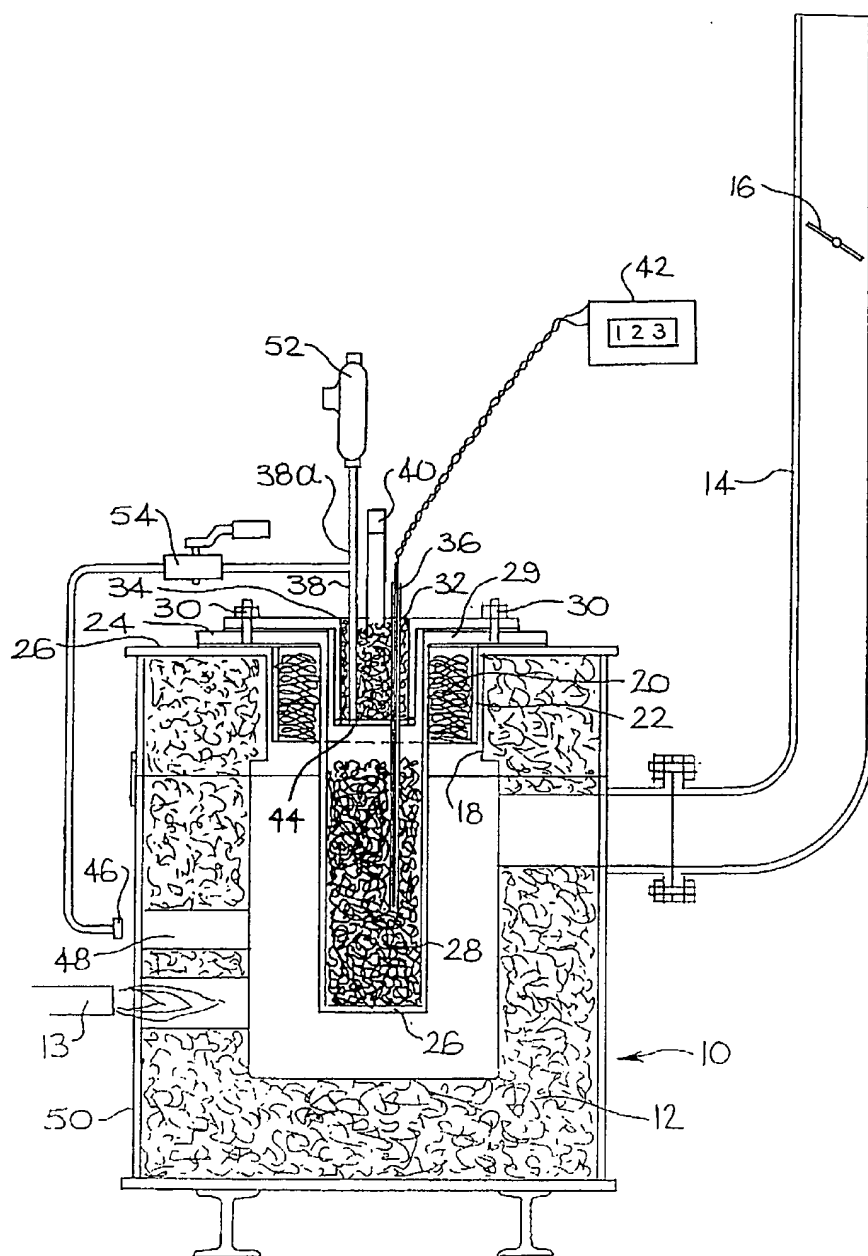
30 24. The composite body of claim 22 or claim 23, wherein the flux precursor comprises uncalcined limestone fines.



25. The composite body of any one of claims 22 to 24, wherein the amount of flux or flux precursor is less than or equal to 1/2 part by weight per part of metal oxide.
- 5 26. The composite body of any one of claims 20 to 25, wherein the metal oxide fines comprise ore fines and/or mill scale.
27. The composite body of any one of claims 20 to 26, wherein the metal oxide fines include iron oxide bearing waste material.
28. The composite body of any one of claims 20 to 27, wherein the
- 10 carbonaceous material is finely divided brown coal or peat.
29. The composite body of any one of claims 20 to 28, wherein the metal oxide fines are iron oxides which are to be reduced to steel and the amount of carbonaceous material is further sufficient to provide the desired amount of carbon in the steel.
- 15 30. The composite body of any one of claims 20 to 29, wherein the amount of carbonaceous material in the composite body is at least 1/2 part by weight per 1 part of metal oxide.
31. The composite body of any one of claims 20 to 30, wherein the amount of carbonaceous material in the composite body is between 2/3 and 2 parts by
- 20 weight per 1 part of metal oxide.
32. The composite body of any one of claims 20 to 31, wherein the metal oxide fines have a particle size of less than 1500µm.
33. A composite for use in a metal smelting operation, substantially as herein described with reference to Example 1 or 2.
- 25 34. A process for the reduction of metal oxide fines to a metal containing product, substantially as herein described with reference to Example 1 or 2.
35. An apparatus for use in a process for reducing metal oxide fines to metal, substantially as herein described with reference to the accompanying drawing.

30 DATED: 30 November, 1998
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